XXIX. *Aſtronomical Obſervations relating to the Mountains of the Moon. By Mr.* Herſchel *of* Bath. *Communicated by Dr.* Watſon, *Jun. of* Bath, *F. R. S.*

Read May 11, 1780.

AT the time when the teleſcope was firſt invented this noble inſtrument was immediately applied to aſtronomical obſervations with the moſt ſurpriſing ſucceſs. Several very eminent perſons have given us an account of their diſcoveries; and, notwithſtanding the imperfect ſtate of teleſcopes in thoſe times, we ſtill owe a great deal of our knowledge of the heavenly bodies to the obſervations that were made by thoſe firſt teleſcopic obſervers, who made amends for the deficiencies of their inſtruments by their uncommon diligence and attention.

It may, perhaps, be eſteemed to be a mere matter of curioſity to ſearch after the height of the lunar mountains. I grant that there are more neceſſary and more uſeful objects of inquiry in the ſcience of aſtronomy; but when we conſider that the knowledge of the conſtruction of the Moon leads us inſenſibly to ſeveral con-

ſequences, which might not appear at firſt; ſuch as the great probability, not to ſay almoſt abſolute certainty, of her being inhabited, we ſhall ſoon agree, that theſe reſearches are far from being trifling.

My reaſon for repeating obſervations that have been made by very good aſtronomers was not that I doubted either their veracity or diligence. The names of GALILEO, HEVELIUS, KIRCHER, and ſeveral more, will always deſerve to be mentioned with particular reſpect for the eminent ſervices they have rendered to aſtronomy; but as we know that their inſtruments were far from being arrived to that degree of perfection we have now obtained, I thought it by no means improper or uſeleſs to repeat their obſervations on the lunar mountains, and to extend them to other parts of the Moon's viſible hemiſphere, and thereby to eſtabliſh this theory on the firmeſt evidence of a ſurvey taken by a very excellent inſtrument.

The method uſed by HEVELIUS and others to find the height of a mountain in the Moon is this. Let a ray of light SLM (fig. 1.) proceeding from the Sun, paſs by the Moon at L, and touch the top of a mountain at M: then the ſpace between L and M will appear dark, and the top of the mountain will be ſeen to ſtand at ſome diſtance from the illuminated part of the Moon's diſk. With a

good micrometer let the diſtance LM be taken by obſervation[(a)]. Draw LC perpendicular to LM; draw alſo MC from the top of the lunar mountain to the center of the Moon: then in the triangle MLC, rectangled at L, we have given the ſide LC, which is the Moon's radius, and the ſide LM taken by obſervation. Therefore, by trigonometry, we can find the hypothenuſe MC[(b)], from which, ſubtracting the part *p*C or radius, there remains the perpendicular height of the mountain M*p*. I have followed the ſame method, as being the leaſt liable to error.

GALILEO takes the diſtance of the top of a lunar mountain from the line that divides the illuminated part of the diſk from that which is in the ſhade to be equal to a 20th part of the Moon's diameter; but HEVELIUS affirms, that it is only the 26th part of the ſame.

When we calculate from thence the height of ſuch a mountain it will be found, in Engliſh meaſure, according to GALILEO, almoſt $5\frac{1}{2}$ miles; and, according to HEVELIUS, ſomething more than $3\frac{1}{4}$ miles, admitting the Moon's diameter to be 2180 miles.

(*a*) I do not recollect that HEVELIUS mentions in what manner he took the diſtance LM; but I am apt to believe it was by a micrometer.

(*b*) $\sqrt{\overline{LC}^2+\overline{LM}^2}=MC$.

He says, in his Selenography, p. 266. "Vera distan-"tia illustratarum cuspidum, à confinio luminis et um-"bræ, præsertim tempore quadraturæ, invenitur, unâ "vigesimâ sextâ parte, totius Lunæ dimetientis con-"stare; quando nimirum sunt remotissimæ: quemad-"modum hoc ex phasi trigesimâ secundâ, monteque "Apennino; ex phasi trigesima prima, monteque Di-"dyme; et trigesimâ phasi, monteque Tauro et Anti-"tauro, manifestissimè demonstratur." Having afterwards mentioned that GALILEO makes the distance LM to be the 20th part of the Moon's diameter, HEVELIUS proceeds, "Quamobrem, cum distantiæ a nobis designatæ, "paululum sint minores, idcirco et montes aliquantu-"lum depressiores inveniuntur, quàm GALILÆUS æsti-"mavit: neque non tamen illi terrenis nostris montibus, "quoad altitudinem, non solum æquiparari possunt meri-"tissimò; sed et multo certe sunt excelsiores, quàm "nostri omnium maximi; prout confestim, ex adjecto "diagrammate patebit." He gives us then his calculation according to German and Italian measure; and having found, in the manner above mentioned, the hypothenuse MC, he adds: "Semidiameter Lunæ erit 1976 "octav. part. Si igitur hæc à totâ hypothenusâ aufere-"tur, restabunt adhuc sex, hoc est sex octavæ unius mil-"liaris, vel tres quartæ unius milliaris Germanici, sive

"tria

"tria milliaria Italica: quæ eſt vera, et genuina altitudo "iſtius montis." As a German mile in the time of HEVELIUS was a very uncertain meaſure, we may ſuppoſe that he meant geographical miles, 15 of which make a degree of latitude. The obſervations of HEVELIUS have always been held in great eſteem; and this is moſt probably the reaſon why later aſtronomers have not repeated them. M. DE LA LANDE, who is one of our moſt eminent modern aſtronomers, agrees to the ſentiments above cited.

In his *Abrégé d'Aſtronomie*, p. 435. he ſays, "Je terminerai ce qui concerne la ſelenographie, en diſant un "mot de la hauteur des montagnes de la lune, qui étoient "quelquefois éclairées, quoiqu' éloignées de la ligne de "lumière de la treizième partie du rayon de la Lune; de "la on peut conclure que ces montagnes ont de hauteur "la 338^{ieme} partie du rayon Lunaire, ou une lieue de "France. He then gives us a particular calculation, and the reſult is: "Avec ces données on trouve la hauteur de "2643 toiſes, c'eſt à dire, plus d'une lieue commune."

He alſo mentions the opinion of GALILEO, and adds: "Mais on doit préférer à cet égard les obſervations "d'HEVELIUS, qui ont été plus répétées, plus détaillées "et plus exactes."

Mr.

Mr. FERGUSON says (Astronomy explained, § 252.) "Some of her mountains, by comparing their height "with her diameter, are found to be three times higher "than the highest hills on our earth."

KEILL, in his Astronomical Lectures, has calculated the height of St. Katherine's hill, according to the observations of RICCIOLUS, and finds it nine miles.

Before I report my own observations, it will be necessary to explain by what method I have found the height of a lunar mountain from observations that were made when the Moon was not in her quadrature; for the method laid down by HEVELIUS will only do in that one particular case: in all other positions the projection of the hills must appear much shorter than it really is. Let SLM, or *slm* (fig. 2.) be a line drawn from the Sun to the mountain, touching the Moon at L or *l*, and the mountain at M or *m*. Then, to an observer at E or *e* the lines LM, *lm*, will not appear of the same length, though the mountains should be of an equal height; for LM will be projected into *on*, and *lm* into ON. But these are the quantities that are taken by the micrometer when we observe a mountain to project from the line of illumination. From the observed quantity *on*, when the Moon is not in her quadrature, to find LM we have the following analogy. The triangles *o*OL, *r*ML, are similar; therefore,

therefore, $Lo : LO :: Lr : LM$, or $\frac{LO \times on}{Lo} = LM$; but LO is the radius of the Moon, and *Lr*, or *on*, is the obſerved diſtance of the mountain's projection; and *Lo* is the ſine of the angle ROL = *o*LS, which we may take to be the diſtance of the Sun from the Moon without any material error, and which therefore we may find at any given time from an ephemeris.

I will now give an account of my own obſervations relating to the mountains in the Moon; but, perhaps, it may not be amiſs to mention the inſtrument they were made with, and a few of the circumſtances, that it may appear how far their accuracy may be depended upon.

The teleſcope I uſed was a Newtonian reflector of ſix feet eight inches focal length, to which a micrometer was adapted conſiſting of two parallel hairs, one of which was moveable by means of a fine ſcrew. The value of the parts ſhewn by the index was determined by a trigonometrical obſervation of a known object at a known diſtance, and was verified by ſeveral trials. The power I always uſed, except when another is mentioned, was 222 times, alſo determined by experiment, which I have often found to differ ſomewhat from theory, on account of ſome little errors in the *data*, hardly to be avoided. The moon having ſufficient light, I uſed no more

more aperture of the object ſpeculum than four inches; and, I believe, that for diſtinctneſs of viſion this inſtrument is perhaps equal to any that was ever made.

OBSERVATIONS.

November 30, 1779, ſix o'clock in the morning, a rock, ſituated near what HEVELIUS calls *Lacus niger major*, was meaſured to project 41″,56. To reduce this quantity into miles, put R for the ſemi-diameter of the Moon in ſeconds, as given by the Nautical Almanac at the time of obſervation, and Q for the obſerved quantity, alſo in ſeconds and centeſimals; then it will be in general $R : 1090 :: Q : \frac{1090 Q}{R} = on$, in miles. Thus it is found that 41″,56 is 46,79 miles. This diſtance of the Sun and Moon at the ſame time was, by the Nautical Almanac, about 93° 57′$\frac{1}{2}$. The ſine of which to the radius 1 is .9985, &c. and $\frac{on}{Lo}$ in this caſe, is $LM = 46{,}85$ miles. Then, by HEVELIUS's method the perpendicular height of the rock is found to be about one mile.

The ſame morning, a great many rocks, ſituated about the middle of the diſk, projected from 25″,93 to 26″56. This gives *on* about 29,3 miles, and theſe rocks are all leſs than half a mile high.

January

January 13, 1780, 7 o'clock, I examined the mountains in the Moon; but there was not one of them that was fairly placed on level ground, which is a condition very neceſſary for an exact meaſurement of the projection. If there ſhould be a declivity on the Moon before the mountains, or a tract of hills placed ſo as to caſt a ſhadow on that part before them which would otherwiſe be illuminated, it is plain that the projection would appear too large; and, on the contrary, ſhould there be a riſing ground before them, it would appear too little.

As far as I was able to judge of the direction of the line of illumination, the higheſt hill projected 25″31, or 30,36 miles: from thence we find, as before that the perpendicular height is (.42 mile) leſs than half a mile.

January 14, 11 o'clock, I took the projection of the higheſt mountain which was ſituated at the Weſtern edge. It meaſured 24″,68, or about 27 miles; and the perpendicular height comes out leſs than half a mile. There was not one mountain in the edge of the diſk ſo high as this.

January 17, 7 o'clock, a very high mountain projected no leſs than 40″,625. Its ſituation is in the South-eaſt quadrant. The Moon's ſemi-diameter, at the time of

 obſervation,

obſervation, by the Nautical Almanac, was 16′ 2″,6; therefore, $\frac{1090\,Q}{R}$ = 45,98 miles = *on*.

	s	°	′	″
Sun's longitude at 7h. . .	9	27	39	0
Moon's longitude at 7 . .	2	2	46	52
Their neareſt diſtance, . .	4	5	7	52

or about 125° 8′; the ſine of which is .8104: thence we find LM 56,73 miles; and the perpendicular height of the mountain is 1m. 47, or leſs than a mile and a half.

January 22, 8h. 20′. the higheſt mountain, ſituated near Snell or Petavius, projected 11″,437, which is 12′,34; and LM comes out to be 35,3 mile: threfore the perpendicular height is ,57 mile.

Another, juſt behind Mare Criſium, meaſured only 7″, therefore is leſs than half a mile high.

January 25, 7h. 30′. in the morning, a mountain near Ariſtoteles meaſured 18″,59 which gives 20,6 miles; and LM is found 28,53 miles; the perpendicular height is therefore only ,37 mile.

Other mountains about Mare Nectaris meaſured about 23″,5; but they had hills before them, and their ſituation was not ſo proper for my purpoſe. However, it is evident they were of no conſiderable height.

January 28, 6 o'clock in the morning, the higheſt mountain in the diſk meaſured $30'',937$; the Moon's ſemi-diameter at that time $15'\ 40''$; and *on* therefore equal 31,37 miles: but as the Moon is within four hours of her quadrature we may be aſſured that this mountain is leſs than half a mile high.

February 19, Mons Sinopium projected $5'',781$; therefore $on = 6,26$ miles, and the quantity LM 56,54 miles; and conſequently the height of this mountain, which it ſeems proves to be a very high one, is not much leſs than a mile and a half. However, my journal obſerves, that the meaſure was very full; therefore the mountain in all probability does not exceed a mile and a quarter. Moreover, I think that obſervations made ſo near the full or new Moon are leſs to be depended upon, becauſe a ſmall error in meaſuring will produce a great one in the height of a mountain.

From theſe obſervations I believe it is evident, that the height of the lunar mountains in general is greatly over-rated; and that, when we have excepted a few, the generality do not exceed half a mile in their perpendicular elevation. It is not ſo eaſy to find any certain mountain exactly in the ſame ſituation it has been meaſured in before; therefore ſome little difference muſt be expected in theſe meaſures. Hitherto I have not had an

 oppor-

opportunity of particularly obſerving the three mountains mentioned by HEVELIUS; nor that which RICCIOLUS found to project a ſixteenth part of the Moon's diameter. If KEILL had calculated the height of this laſt mentioned hill according to the theorem I have given, he would have found (ſuppoſing the obſervation to have been made, as he ſays, on the fourth day after new Moon) that its perpendicular could not well be leſs than between eleven and twelve miles.

I ſhall not fail to take the firſt opportunity of obſerving theſe four, and every other mountain of any eminence; and if other perſons, who are furniſhed with good teleſcopes and micrometers, would take the quantity of the projection of the lunar mountains, I make no doubt, but that we ſhould be nearly as well acquainted with their heights as we are with the elevation of our own. One caution I would beg leave to mention to thoſe who may uſe the excellent $3\frac{1}{2}$ feet refractors of Mr. DOLLOND. The admirable quantity of light, which on moſt occaſions is ſo deſirable, will probably give the meaſure of the projection ſomewhat larger than the true, if not guarded againſt by proper limitations placed before the object glaſs. I have taken no notice of any allowance to be made for the refraction a ray of light muſt ſuffer in paſſing through the atmoſphere of the Moon, when

when it illuminates the top of the mountain, whereby its apparent height will be leſſened, as we are too little acquainted with that atmoſphere to take it into conſideration. It is alſo to be obſerved, that this would equally affect the concluſions of HEVELIUS, and therefore the difference in our inferences would ſtill remain the ſame.

Bath, February 28, 1780.

Continuation of the ſame obſervations.

March 11, 1780, 7h. Promontorium Archeruſia projected 17″,187. It is very properly ſituated for meaſuring. By a proper deduction from the Moon's ſemidiameter, as given by the Nautical Almanac, at the time of obſervation, we find the quantity $on = 20.1$ miles, and LM 22,6 miles; from which it appears, that the perpendicular height of this mountain is a little leſs than a quarter of a mile.

Antitaurus, the mountain meaſured by HEVELIUS was badly ſituated, becauſe Mount Moſchus and its neighbouring hills caſt a deep ſhadow, which may be miſtaken for the natural convexity of the Moon. A good, full, but juſt meaſure, 25″,105; in miles 29,27: therefore,

LM ;

LM 31,7 miles, and the perpendicular height not quite half a mile.

7h. 45′. I was deſirous of being very exact in this meaſure, therefore I repeated it. I took two different obſervations. A narrow meaſure 21″,562; quite full enough 24″,062. Theſe meaſures give the perpendicular height leſs than half a mile.

8h. I meaſured Lipulus, 19″063. It is alſo badly ſituated, though rather better than Antitaurus. I found that the projection increaſed, therefore concluded that this was not the higheſt part of the mountain, and waited ſome time when I meaſured it again.

9h. Lipulus now projected 28″,75.

10h. It meaſured 28″,75: this gives *on* = 33,64 miles. Diſtance of Sun and Moon about 63° 23′: therefore, LM 37,54 miles. From hence we find the perpendicular height ,64 mile, or very near two-thirds of a mile.

March 12, 1780, 7h. One of the Apennine mountains, between Lacus Traſimenus and Pontus Euxinus projected 44″,062. This gives us *on* = 51,11 miles; and LM = 52,9 miles: therefore the perpendicular height of theſe mountains, which I know to be very high, comes out to be 1¼ mile.

Mons

Mons Armenia (near Taurus) projected 31″406 = 36,43 miles; LM = 38 miles nearly, and the height two-thirds of a mile.

Mons Leucopetra 34″479 or 40 miles; LM = 41,4 miles, and the perpendicular height three quarters of a mile.

There was a very fine ſhade of a high rock near it, which ſhewed the direction of the illuminating ray, and thereby aſſiſted me in meaſuring to a great exactneſs; but the mountain itſelf is not very favourably ſituated.

March 16, 10h. 30′. Mons Lacer projected 45″,625; but I am almoſt certain that there are two very conſiderable cavities or places where the ground deſcends below the level of the convexity, juſt before theſe mountains, ſo that theſe meaſures muſt of courſe be a good deal too large: but ſuppoſing them to be juſt, it follows, that *on* is 50,193 miles, LM = 64 miles, and the perpendicular height above 1¾ miles.

Another of the ſame mountains ſituated on the borders of S. Sirbonis meaſured 41″,875. This ridge of mountains is the ſame of which I meaſured one on January the 17th, which was then found to be 1,47 miles high.

The

The following additional Memoranda of the Manner in which Mr. HERSCHEL *made his Observations are taken from a Letter of his to the rev. Dr.* MASKELYNE, *Astronomer Royal.*

IN the second figure of my observations, the points L, S, E, *r*, are all supposed to be in one plane; and as the illuminating ray SL is also in this plane, it follows, that the line L*n* (= *on*) will always be perpendicular to the right line which joins the cusps of the Moon [(c)]; and the truth of the theorem there delivered depends upon this circumstance.

For this reason I have taken care in all my observations to measure the line, which in fig. 3. (taken from your letter to Dr. WATSON) is marked *on*, parallel to the line CD, or perpendicular to AB, and not the line *rn*, perpendicular to the elliptical curve A*ro*B.

The manner of taking it is easy enough: however, I have occasionally used three different methods, and will de-

(*c*) It is here supposed, that rays from the Sun S, and the eye of the observer E, to any part of the Moon L, may be taken for parallel; and therefore, that different planes, made by several sections of the Moon, according as the point L is taken North or South of the diameter of the Moon, which is at rectangles to the line joining the cusps, may also be taken to be parallel to that diameter.

scribe

ſcribe them all, which I ſhould have done in the paper delivered by Dr. WATSON, had I not feared to be too particular.

The firſt method I uſed was to ſet the immoveable hair *bb* (fig. 4.) of my micrometer parallel to a line AB, joining the cuſps of the Moon; then, by opening the moveable parallel hair till it included the projection *on*, intended to be taken, I marked that down as the meaſure of *on*. As this method required ſome attention (that part of the ellipſis of illumination AVB which is the vertex V of the leſſer axis may ſerve as a direction) and took up ſome time, on account of the ſmall field of view of my teleſcope, I uſed occaſionally theſe two following ways.

When there was any remarkable figure on the diſk of the Moon near the line of illumination, I put on a compound eye-piece whoſe magnified field of view is full 40°, and power about 90 times, ſo that it takes in the greateſt part of the whole Moon; by this means I was enabled to view the projection intended for meaſuring at the ſame time with the reſt of the Moon, and to fix upon ſome mark in the diſk very near to its edge towards which I judged the line *on* ſhould be directed; then putting on the eye-piece which carries the micrometer I

took the diſtance according to this judgment as well as I could.

The third method I took was the following, which, indeed, I look upon as the beſt of all, and which I therefore moſt frequently put in practice. I took a view of ſome neighbouring ſhades of rocks or mountains, if there happened to be any near, and directed the meaſure of the micrometer by them, as they plainly pointed out the direction of the illuminating ray; or, which is the ſame thing, indicated the line perpendicular to a line joining the cuſps.

Mons Leucopetra was meaſured by this laſt method, which circumſtance I have mentioned in my obſervations of the 12th of March, where I ſaw the whole rock and its higheſt point, as well as the whole ſhade, and its laſt termination, upon very even ground, at the ſame time that I directed my micrometer in that line, to take the projection *on*, of the above mentioned mountain.

Sometimes I compared together a meaſure taken in the direction *on*, and one taken in the direction *rn*; but as moſt of my obſervations were made upon mountains not ſituated near the cuſps or limb of the Moon, I never found ſo much difference between theſe two meaſures, that it could have occaſioned any very material error, if I had intirely neglected it.

By the nature of the ellipsis it will appear, that, when we do not come too near the limb or cusps of the Moon, a tangent drawn to a point in the curve of illumination will seldom make with the subtangent an angle that exceeds (or is so much as) 26°; and in all such cases the error that can arise from taking the line *rn* instead of *on* will be less than the tenth part of the whole measure: but, if the angle the tangent makes with the subtangent is only about 18°, the error will be less than a 20th part; and all the measures I have taken, I believe, will be found to be much within these last-mentioned limits. From this consideration it will appear, that if I had not been aware of this circumstance, my observations would still be sufficiently accurate to disprove the usually assigned great height of the lunar mountains; but as I took all the precaution the situation of each mountain would afford, by using any one of the above mentioned three methods, which suited best, I believe there can hardly be a possibility of any error that should amount to a 40th part of the whole height of any mountain I have measured.

The figure ABCD (fig. 5.) contained by the diameter AB, the arch CD, and the two curve AD, BC, shews in what portion of the Moon's semi-disk we may safely measure the line *rn*, instead of *on*, without being liable

to ſo great an error as one tenth part of the whole, and the figure AB cd contains that part wherein the meaſure rn being taken inſtead of on, the error will be leſs than the 20th part of the whole meaſure. In a portion ſomething more confined the error will ſoon vaniſh, ſo that the difference may be ſafely neglected intirely. Thus in the ſpace AB xy the error cannot amount to a hundredth part. Theſe figures may be conſtructed by taking the ſeveral points D, d, y, and C, c, x, 26°, 18°, 8°, reſpectively, from the vertex, the curves AD, Ad, Ay, BC, Bc, Bx, being the loci of thoſe points of the tangents which touch the ſeveral ellipſes of illumination that may be contained in the ſemi-diſk of the Moon, when theſe tangents make thoſe ſeveral angles of 26°, 18°, 8°, with their ſubtangents.

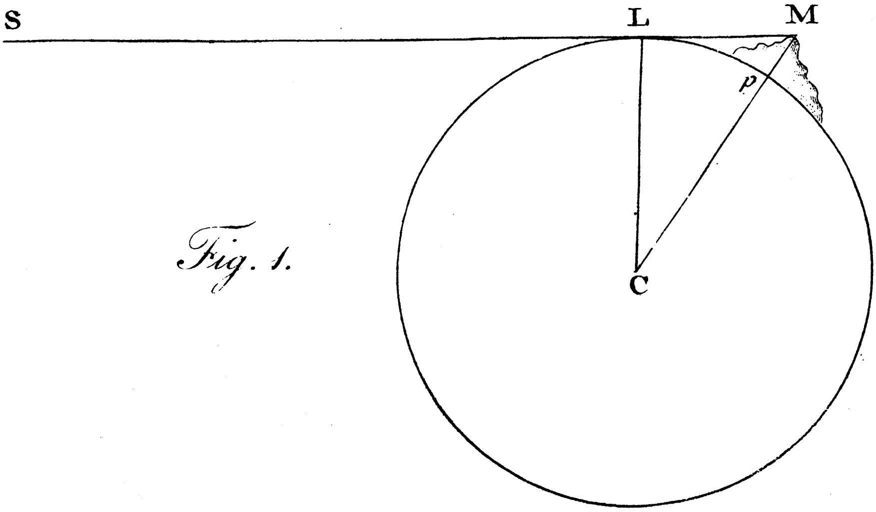
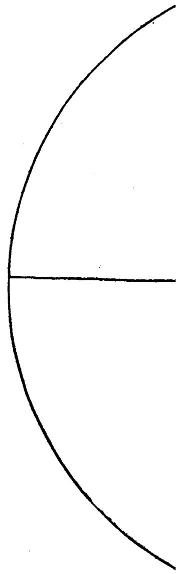


Fig. 1.



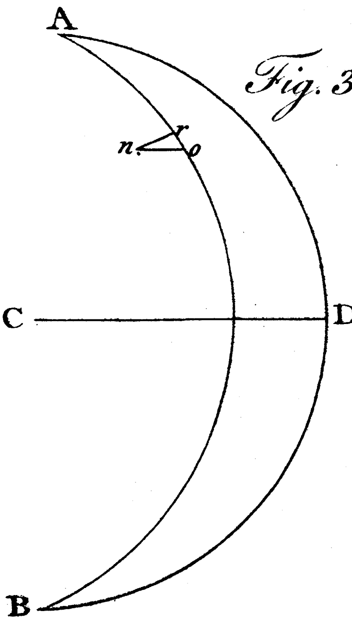


Fig. 3.

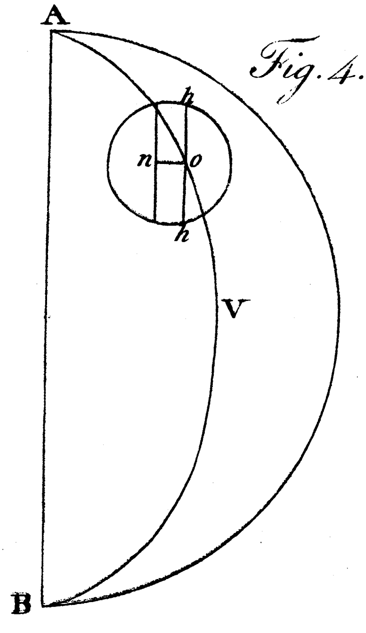
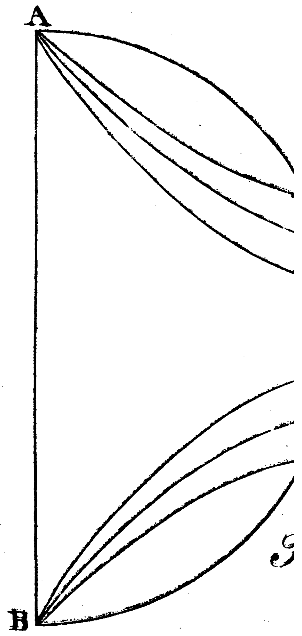


Fig. 4.



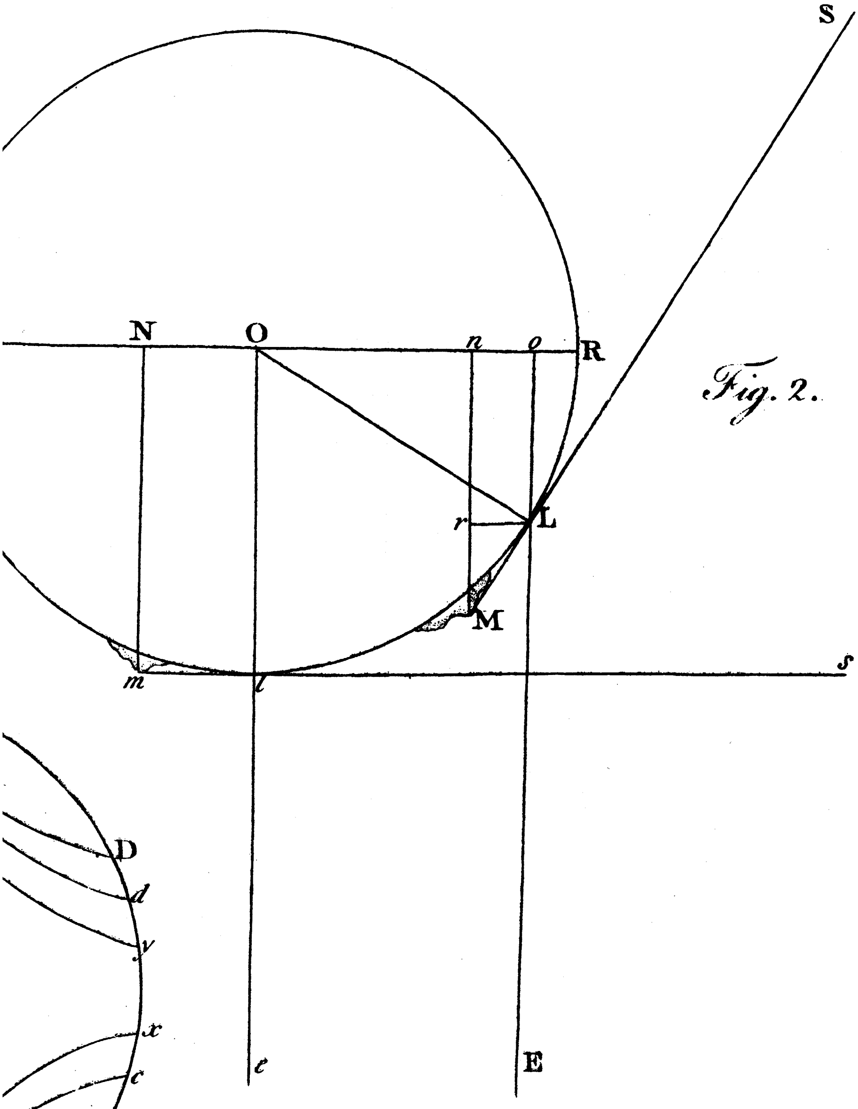


Fig. 2.

Fig. 5.

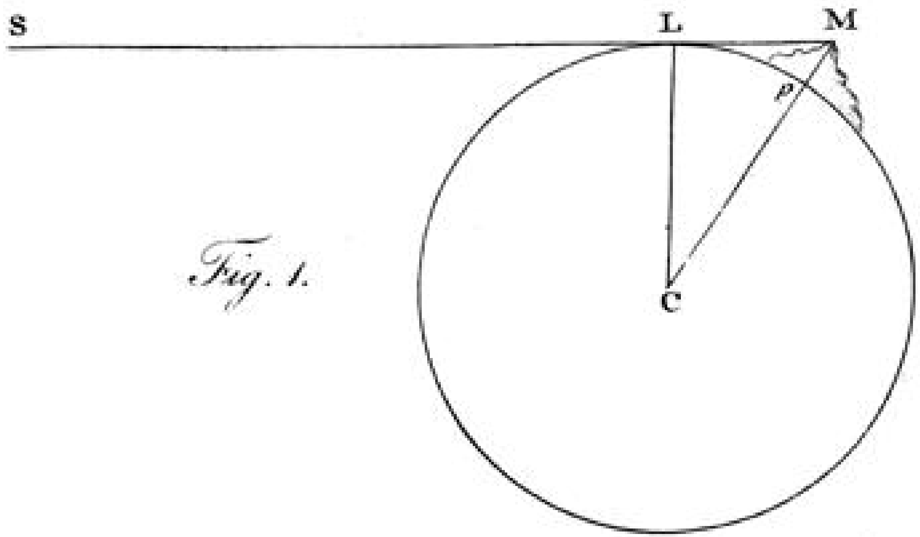


Fig. 1.

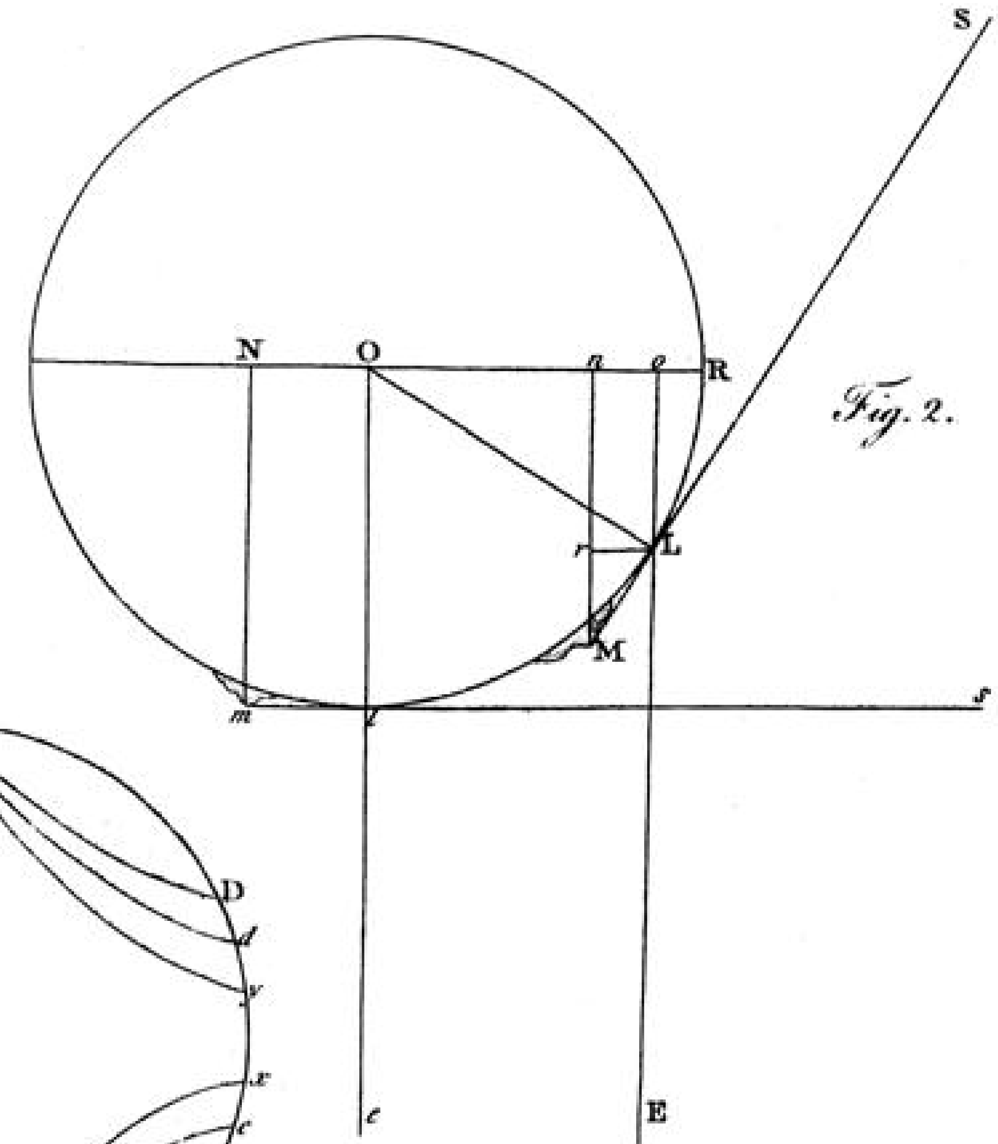


Fig. 2.

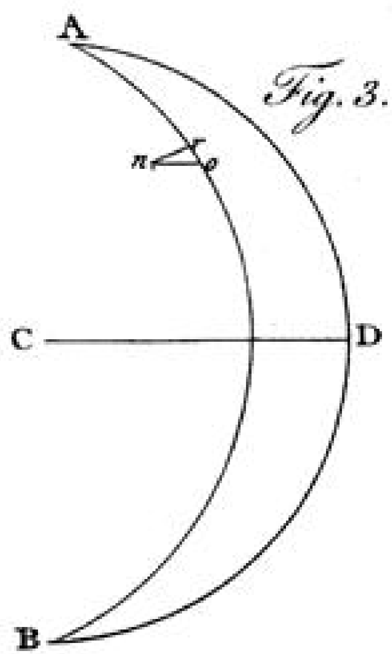


Fig. 3.

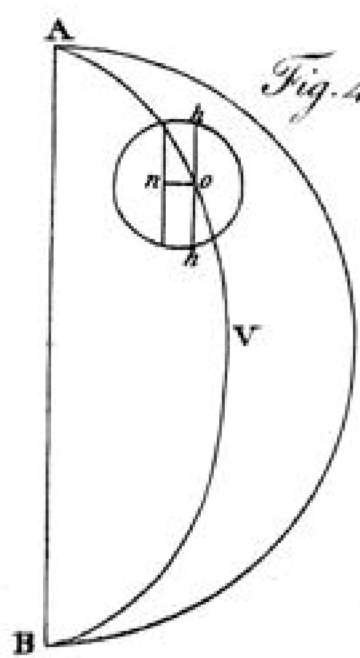


Fig. 4.

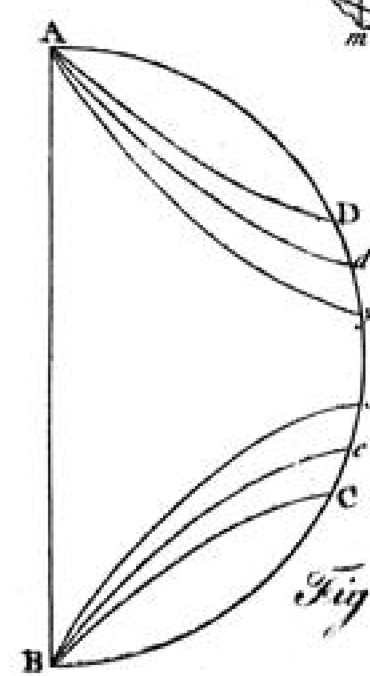


Fig. 5.